

VII. MICROWAVE AND MILLIMETER WAVE TECHNIQUES

Academic and Research Staff

Prof. Bernard F. Burke
Prof. Madhu S. Gupta

Prof. Robert L. Kyhl
Prof. Paul L. Penfield, Jr.

Prof. David H. Staelin
Dr. Alan Parrish

Graduate Students

John Cooley
John F. Cooper
Patrick C. Crane
Thomas S. Giuffrida

Lance A. Glasser
Aubrey D. Haschick
Syed A. Moinuddin

Gary K. Montress
Edward D. Nowak
Felipe D. Ramon y Alarcon
Robert C. Walker

1. LOW-TEMPERATURE MILLIMETER WAVE RECEIVERS

Joint Services Electronics Program (Contract DAAB07-75-C-1346)

a. Low-Barrier Cryogenic Diodes

Lance A. Glasser, Robert L. Kyhl

This program is directed toward the development of receivers with a low noise figure by the use of cryogenic devices and techniques. The effort devoted to mixers has two immediate goals: to design a low-noise mixer and to develop a technique for the precise measurement of the parameters of a microwave mixer.

In the past year we carried out studies of the properties of conventional Schottky diode mixers at low temperature, but concluded that a greater potential for improvement in performance could be expected from two other devices, because of a sharper nonlinearity in their I-V characteristic. These devices, which we are now studying, are the superconducting Schottky junction, and the n^+nn^+ diode, a cryogenic device related to the cryosar.¹ This device, described in Progress Report No. 116 (page 53), operates at voltages intermediate between conventional Schottky barrier mixer diodes and the millivolt level of the superconducting Schottky devices. The microwave properties of the device are largely unexplored, and we are carrying out microwave measurements on the devices that have been fabricated. Investigation is also in progress to determine whether these devices have useful low-noise properties.

Studies are being made of bridge techniques for measuring the small-signal scattering parameters of mixers. The phase angles of the S-parameters are also being measured. The need for this measurement arises because a nonlinear pumped resistive device is a nonreciprocal circuit element, while the usual phase angle measurement methods assume it to be reciprocal.

References

1. A. L. McWhorter and R. H. Rediker, Proc. IRE 47, 1207 (1959).

JSEP

JSEP

(VII. MICROWAVE AND MILLIMETER WAVE TECHNIQUES)

JSEP b. Low-Noise GaAs FET Amplifier

John F. Cooper, Madhu S. Gupta

The goal of this project is to design, construct, and test a low-noise microwave amplifier built with gallium arsenide field-effect transistors cooled to 77°K. The amplifier is used as the IF amplifier stage in the low-temperature millimeter-wave receiver. Four tasks have been completed: selection of the signal and noise models for the microwave FET, device measurements and characterization, study of the effect of cooling, and optimization of the GaAs FET amplifier design. The construction of the amplifier is now in progress, after which the testing and evaluation will be carried out.

The signal and noise model is that of Statz et al.¹ This model was applied to a GaAs FET, and the device was characterized in terms of structural dimensions and doping. From this model the values for the intrinsic FET equivalent circuit elements were calculated, and parasitic elements were determined either by calculation or measurement. The noise model was used to predict the optimum noise figure and source impedance. A model for the device package was obtained from microwave measurements made in calibration packages. The effects of the package upon signal and noise properties were calculated; in general, the package decreased the available gain of the device and reduced its noise measure. An amplifier has been designed to achieve optimum noise measures. The effects of cooling on the device were studied by measuring and calculating the device parameters at room and liquid nitrogen temperatures in an effort to reduce noise. At 77°K temperature, the packaged device has a noise measure of 0.23 calculated from the noise model. This work is described in detail in a thesis to be presented to the Department of Electrical and Computer Engineering, M. I. T.²

References

1. H. Statz, H. Haus, and R. Pucel, "Noise Characteristics of Gallium Arsenide Field-Effect Transistors," IEEE Trans., Vol. ED-21, No. 9, pp. 549-562, September 1974.
2. J. F. Cooper, "A Low-Noise Microwave GaAs Amplifier," S.B. and S.M. Thesis research.

2. ACTIVE MICROWAVE SOLID-STATE DEVICES

Joint Services Electronics Program (Contract DAAB07-75-C-1346)

a. Linearity of Multistage Amplifiers

Madhu S. Gupta

The objective of this work is to find methods for improving the linearity of the transfer characteristic of microwave amplifiers. In applications where the nonlinearity manifests itself as saturation, thereby limiting the obtainable power output and reducing the gain, this effect can be described in terms of gain compression, which is a single-frequency characterization of nonlinearity.

In broadband applications, a multifrequency characterization of the nonlinearity is essential and the design should be optimized to reduce intermodulation distortion.

JSEP Several techniques for reducing gain compression have been developed, including the compensation method¹ and the optimum gain distribution method.² Work is being carried

out to develop parallel methods of optimizing amplifier design by using the intermodulation products as the criterion.

JSEP

References

1. M. S. Gupta, "Design of Multi-Device Negative-Resistance Amplifiers with Optimal Linearity," Proceedings of the Fifth Biennial Conference on Active Semiconductor Devices for Microwave and Integrated Optics, School of Electrical Engineering, Cornell University, Ithaca, New York, August 1975.
2. M. S. Gupta, "Selection of Stage Gains in a Multistage Amplifier for Minimum Overall Gain Compression" (in preparation for publication).

b. Stability of Negative-Resistance Amplifiers

Madhu S. Gupta

At low frequencies it is customary to calculate or measure the transfer function of an amplifier over a very wide frequency range (effectively 0 to ∞) and then apply the stability criterion to determine if it is unstable, conditionally stable, or absolutely stable. At microwave frequencies where the fractional bandwidths are small by comparison, the likely frequency of oscillation is known in advance. A stability factor is usually defined in terms of the two-port parameters at this frequency and its magnitude determines whether the amplifier is unstable, potentially unstable, or inherently stable. A new stability factor has been obtained that can be found in terms of the port parameters, and therefore is related to the earlier stability factors such as Stern's and Rollet's. It has three advantages over theirs: (i) It has a very simple and intuitive interpretation in terms of the impedance of the active one-port (negative-resistance) device. (ii) This interpretation leads to a direct method of determining the stability factor algebraically from the device impedance or graphically by using the Smith chart. (iii) The tradeoff between the gain and the stability of the amplifier becomes evident because a "gain-stability factor product" that is constant can be determined. This work is fully described in a forthcoming publication.¹

References

1. M. S. Gupta, "A New Stability Factor for Negative-Resistance Amplifiers" (in preparation for publication).

c. Fabrication and Characteristics of Microwave BARITT Diodes

Gary K. Montress, Madhu S. Gupta

BARITT (Barrier Injection and Transit Time) diodes have been successfully fabricated. These devices incorporate a Schottky barrier as the injecting contact, and a reverse-biased p-n junction as the collecting contact. The Schottky barrier metal is aluminum, and the devices are mesa diodes. They are packaged in standard "varactor" microwave diode packages.

In measurements made on packaged devices tuned as oscillators in a cavity, the best performance to date has been the following:

Run 1 devices $P_{out} = 14$ mW at 5.3 GHz frequency and 1.6% efficiency.

JSEP

(VII. MICROWAVE AND MILLIMETER WAVE TECHNIQUES)

JSEP

Run #2 devices $P_{out} = 1$ mW at 6.7 GHz frequency and 0.6% efficiency.

More devices will be fabricated to try to improve this performance. Experiments are under way to measure the small-signal impedance as a function of frequency and bias level. Other measurements that will be performed include noise figure and gain of reflection amplifiers incorporating the diodes, and a small-signal circuit model for the devices will be evaluated.

When the BARITT diode is mounted in a cavity and operated as an oscillator or reflection amplifier, a knowledge of the small-signal device impedance is essential. Since all such impedance measurements are made at a reference plane remote from the actual diode chip, however, a knowledge of mount and package parasitic reactances is necessary. At the frequencies of interest in the present work (4-8 GHz) these reactances are important. Measurements were made to ascertain a suitable lumped-element model to represent the package and mount parasitic reactances for later use in de-embedding the device admittance from measured data.

Open- and short-circuit packages were prepared. Five open- and five short-circuit packages were tested. The bonding wire in the short-circuit packages was .001" gold wire. The package is a Metalized Ceramics Type 60-6070. Measurements of the short- and open-circuit package impedance were made every 500 MHz from 4 GHz to 12 GHz. The package was assumed to be lossless. The four-element lumped model shown in Fig. VII-1 was found to give an excellent fit to the experimental data.

The element values represent an average over the five open- and five short-circuit package impedances. A least-mean-square computer fit of the data was used in deriving the element values. A computer program has been written which incorporates this model for the package parasitics and de-embeds the chip admittance from slotted-line impedance measurements made at the package flange.

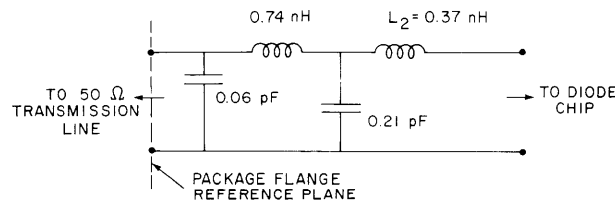


Fig. VII-1. Four-element lumped model.

Since the BARITT diode small-signal impedance is dependent upon the RF signal power incident on the device, it is necessary to make the impedance measurement on a slotted line at very low incident signal power levels, i. e., 0.1 mW or lower. Standard slotted-line techniques will not suffice. The technique proposed by Bandler¹ has been adopted and somewhat simplified. It is extremely accurate, and capable of accurate VSWR measurement at incident signal levels as low as 5 μ W. This system has been calibrated and we have begun measurements on the devices. The results of these measurements of small-signal BARITT impedance, showing how this impedance varies with incident signal level, are expected soon.

References

1. J. W. Bandler, "Precision Microwave Measurement of the Internal Parasitics of Gunn Diodes," IEEE Trans., Vol. ED-15, No. 5, pp. 275-282, May 1968.

JSEP

(VII. MICROWAVE AND MILLIMETER WAVE TECHNIQUES)

3. MICROWAVE MEASUREMENTS AND INSTRUMENTATION

JSEP

Joint Services Electronics Program (Contract DAAB07-75-C-1346)

National Science Foundation (Grant AST73-05043-A02)

Bernard F. Burke, Alan Parrish, Thomas S. Giuffrida, Aubrey D. Haschick,
Robert C. Walker

Interferometric measurements of discrete sources will be made at 22 GHz, in order to make precision determinations of atmospheric refraction and seeing, with accuracy of 0.1 arc second. Both short-term (few seconds) and long-term (hours to days) effects will be studied in all weather conditions.

A 7-mm interferometer with 3 arc-second resolution will be developed, including low-noise cooled front ends of simple design, to extend refraction and seeing measurements to shorter wavelengths. A 3-mm system is the ultimate goal, but the longer wavelength measurements will be made first.

JSEP

